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Small hydro and the environmental implications of its extensive utilization

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A R T I C L E   I N F O

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A B S T R A C T

There is a great resurgence of interest all over the world in the development of 'small' hydropower systems (SHS). The surge is essentially propelled by the belief that SHS, which include mini, micro, and picahydel systems, are a source of clean energy with little or no adverse impacts on the environment. This paper presents an overview of SHS and then examines in detail whether the prevalent belief in the great environment-friendliness of SHS is really justified. It is brought out that widespread use of SHS is likely to cause, per kilowatt of power generated, no less significantly adverse environmental impacts than large hydropower systems and some other conventional sources of energy. While supporting the ongoing global efforts to maximize the use of SHS, the authors advocate much greater circumspection than is being exercised at present *vis-a-vis* SHS. The authors believe that if the likely pitfalls are foreseen before SHS are put to widespread use, and remedial measures taken accordingly, it may save the world from considerable disillusionment and environmental damage.

Contents

1. The general perception about large-scale hydropower projects: how it has changed over the years

1.1. The clean image that once was

Of all the energy sources, hydropower appears, on the face of it, not only among the cleanest but also, arguably, the most versatile. In hydropower generation a benign fluid, water, is used non-destructively; in essence the force of gravity, which is a totally carbon-free and inexhaustible resource, is used to generate energy!

Gravity imparts kinetic energy to water falling from a higher elevation to a lower elevation; the kinetic energy, in turn, is then used to drive a turbine and generate electricity, leaving the water intact and available for all possible uses.

Rivers and streams, big and small, naturally flowing towards lesser elevation provide sites suitable for hydropower generation. If the fall in elevation is sharp, such as in waterfalls, the falling water can be used directly to drive turbines. If the natural fall is not steep, a head is created by damming the river/stream, making a reservoir, and diverting its water to a nearby location with a penstock where the water is made to fall under gravity, driving a turbine. The reservoir also helps to store water when it is available in excess, for use in times when the flow in the stream is too lean or is stopped.

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Unlike thermal power plants there are no gaseous or flyash emissions seen coming out during the production of hydropower. And, unlike nuclear power plants, there are no radioactive wastes to contend with. Nor is any resource consumed because the water used in hydropower generation remains fully intact and utilizable. Creation of reservoirs by damming rivers had also appeared to be a safe and wise strategy because it promised to enable utilizing the river flow to a maximum extent, control floods, and ensure availability of water even when the flow in the feeder river was to dwindle or cease altogether.

Hydropower projects also seem to provide numerous 'side-benefits' not available with thermal or nuclear power generation. Reservoirs can be used for recreation and fish culture without any interference with power generation. The water coming off the turbines can be used for domestic water supply and irrigation.

If one is to simply consider all these virtues, no other technology would appear cleaner, greener, and friendlier than hydropower!

There was a time, during the early 1950s, when all these perceived virtues of hydropower motivated the governments of different countries of those times to go for hydropower generation in a big way. India, which at that time had just won independence (in 1947), and was trying to accelerate its economic development, was among the countries which pinned great hope on large hydropower projects as a source of clean and renewable energy. Indeed, large hydropower appeared such a boon that it was viewed with not only great expectation but even great reverence. This is reflected in the sentiments of the then Prime Minister of India, Jawaharlal Nehru, who called hydropower projects 'temples of modern India'! Whereas developed countries of North America, Western Europe, and Japan accelerated the implementation of their large-scale hydropower generation programmes during the 1950s, increasingly larger dams were also built in other developing countries, notably India, Brazil, China, Malaysia, Thailand, and Turkey.

In the 1960s the High Aswan Dam (HAD) was commissioned in Egypt which, ever since then, has become an iconic symbol of multi-purpose hydropower-cum-irrigation projects.

1.2. The changing image

It was during the mid-1970s, some 20 years after a number of major hydropower projects had been commissioned, that reports began to emerge of the adverse environmental impacts of such projects. It was realized that interference with the hydrology of a river by putting a dam in its midst and converting the upstream portion into a big reservoir did not occur without serious disruptions in all the three major dimensions of environment – physical, chemical, and biological. Rivers and their ecosystems used for hydropower generation were fundamentally transformed due to the fragmenting of channels and alteration in river flows [1]. There were also major socio-economic impacts, several of them traumatic, which resulted from the displacement of a large number of people, and also due to the sudden change in the patterns of resource availability and production capability.

Unlike natural lakes which take hundreds of years for their trophic status to change from oligotraphic to eutrophic, man-made reservoirs underwent this transition within a few years leading to disastrous consequences: degradation in water quality, harm to fisheries, siltation (with concomitant loss of storage capacity), invasion by weeds, and facilitation of the growth of mosquitoes and other disease vectors. Numerous studies, including several by these authors [1–6,28,63] have by now established that adverse impacts are caused by hydropower projects in all the four habitats associated with the projects – the reservoir catchment, the artificially created lake, the downstream reaches of the dammed river, and the estuary into which the river flows.

Hydropower projects are not bereft of benefits; they do generate precious power and boost agricultural production besides often proving to be a sight to behold for tourists, but whether the benefits outweigh the negative impacts remains a question difficult to answer in the affirmative. A very large number of scientists, environmental activists, and members of public believe the answer is in the negative even as a large number of people also voice the opposite opinion. But there is little disputing the fact that hardly anyone today perceives hydropower projects as the epitome of virtue such projects were once believed to be. The International Energy Agency (IEA), which has reported the possible environmental impacts of different renewable energy production systems, lists several negative impacts of major and medium scales that are now widely accepted as being associated with large hydropower projects [7]. Even though IEA is supportive of renewable energy sources in general and large hydropower in particular, it still records that '. . .the negative impacts (of large-scale hydro) can be sufficient to render a project unacceptable or uneconomic'. The USA is one of the countries which went for hydropower in a big way from 1950 onwards, increasing reservoir storage capacity three times to 450 million acre-feet by 1975 [8]. But from then onwards very little further expansion has been done because most suitable undeveloped sites are under federal environmental protection [9] and, consequently, out of bounds for hydropower projects. Moreover environmental regulations are effecting even the existing projects. For example, a series of large facilities on the Columbia River in Washington will probably be forced to reduce their peak output by 1000 MW to save an endangered species of salmon [9]. Most regulated rivers consist of cascades of consecutive reservoirs and impoundments, which constrains possible actions to improve their ecological conditions [1]. The World Bank, which in the early 1970s and 1980s, used to approve more than eight dam-related projects per year, approve less than one per year now. In the USA, the agency responsible for hydropower dam licensing – the Federal Energy Regulatory Commission (FERC) – denied an operational license for a traditional hydropower project for the first time in its over 70-years history in 1993, essentially because of the dam's negative riverine impacts [8]. In all but a few countries, construction of new, large, hydropower dams is considered environmentally harmful, politically unpalatable and simply not viable as an option for increasing renewable energy alternatives [5,8,10].

Among the most disconcerting of the adverse impacts of hydropower projects is emission of greenhouse gases methane and nitrous oxide. These two gases have, respectively, global warming potential 25 and 300 times greater than carbon dioxide [11]. It has been estimated that at least some of the hydropower projects contribute as much to global warming as thermal power projects of equivalent capacity [12]. There are even suggestions that so much methane is generated in the project reservoirs that it can be mined [13,14]. Moreover there is little definitive information on the extent of N_2O emissions but it may be more than is presently anticipated [15]. Hence not only in terms of environmental degradation but also in terms of global warming, hydropower projects do not appear to be significantly better than power projects based on fossil fuels.

It is obvious that the very optimistic, almost reverential, attitude towards hydropower projects which had prevailed during the early 1950s was misplaced. The mistake at that time was to take the perceived virtues for granted and not budget for the possible negative impacts which were likely to surface once a large number of such projects had been commissioned at different locations. Wisdom of hindsight tells us that a great variety of developmental activities appear harmless when tried sporadically because the perturbation such activities cause to the environment get easily assimilated. But once an activity is implemented intensively and repeatedly, across large areas, the environment is not able to absorb or dampen the adverse effects due to their recurrence and collective magnitude

[16]. In the early stages of the industrial revolution, when coal began to be used extensively in place of fuelwood, it (coal) was perceived as a 'clean' fuel because it generated much less smoke and soot than fuel wood. Likewise when petrol and diesel began to fuel locomotives, they appeared much cleaner options compared to coal. In recent years, before global warming became an accepted reality, compressed natural gas (CNG) was viewed as a 'clean' substitute for petrol and diesel. In each of these cases, adverse impacts became apparent once the fuel was used extensively, persistently, and on ever greater scale [17–27]. The world has gone through a similar experience with large hydropower systems.

In the 1950s, when much lesser number of hydroelectric power projects were functioning across the world the adverse impacts did not add up to conspicuous levels. The environmental awareness was also much lesser and the impacts which did occur were not given serious consideration. By mid 1970s the situation had changed dramatically. An increasingly larger number of scientists and environmental activists were coming to believe that far from being 'clean' large hydel may even be the most ecologically damaging of all power generation alternatives [2]. In the 30-odd years that have since elapsed, large hydel hasn't gained any greater acceptance; indeed no sooner the plan of any new hydel project is announced, environmental activists begin resisting it tooth and nail [8,28].

2. The small hydro

The belief widely prevalent at present is that small hydro is a clean substitute for large hydro [8,29]. There is rarely a mention of small hydro without highlighting the belief that small hydro is environmental-friendly [30–35]. Before discussing the environmental aspects of small hydro it may be worthwhile to recapitulate what the term 'small hydro' means.

2.1. What is 'small' hydro?

As the name implies, small hydro is a smaller version of the large hydro. But how to quantify the 'largeness' or 'smallness'? In terms of height of impoundment, storage capacity, power output, or cost of commissioning?

There is no internationally accepted formal definition of small hydro in place as yet, though small hydro is generally taken as a power station/plant having output up to 25 MW. Different agencies use different upper limits for micro and mini hydel projects ranging from 0.1 MW to 2 MW for the former and >0.1 MW to 50 MW for the latter, but a ceiling value of 10 MW is becoming more generally accepted [66], especially in Europe. At the lower end of the scale, technology is available to utilize discharges as small as 200 l/s (0.2 cusec), heads down to 1 m, and a power output of just 0.001 kW with reasonable cost. Some authors call very small (<5 kW) units 'pica-hydro'. Even this scale isn't uniform and some other authors put the upper limit of 'pica-hydro' as 20 kW.

India is one of the few countries in the world with a full-fledged Ministry of New and Renewable Energy (MNRE). As per MNRE [36], small hydropower stations are classified as follows:

(a) Depending on capacity
  Micro: up to 100 kW
  Mini: 101–1000 kW (i.e. 1 MW)
  Small: above 1 MW up to 25 MW
(b) Depending on head
  (i) Ultra low head: below 3 m
  (ii) Low head: above 3 m
  (iii) Medium/high head: above 40 m

Table 1
Upper limits of power generation capacities of 'small hydro' units set by various countries.

Country	Limit (MW)
UK (NFFO)	<5
UNIDO	<10
Sweden	<15
Colombia	<20
Australia	<20
India	≤25
China	<25
Philippines	<50
New Zealand	<50

In Table 1 the upper limit of power generation capacity set by different countries to define smallness of their hydro projects is given.

Broadly, small hydro schemes are of two types – one utilizing small discharges but high heads, and the other utilizing large discharges but smaller heads. These facets also influence the nature of the power generating plants associated with the given site. In high-head units the discharges being small, the physical size of the plant required is also small. In the second type, as the discharges handled are high, the physical size of the generating unit and the power station is consequently quite big. Also for the latter type, proper arrangements for entry of water and its discharge are required to be made. The small hydro development of the first type which is confined mainly to hilly areas is characterized by relatively very simple features of works. The civil works involved comprise a small structure to divert the flow of the hill stream/river, and generally the 'run of river' water-falls is utilized. The power is generally consumed near the site of generation thus precluding requirements of long transmission lines.

In the second type, as the heads available are rather low and discharges have to be comparatively larger to be economically viable, their development can only take place on small rivers, irrigation outlets, canal falls, etc. Their power output is generally connected to the larger power grids.

It must be clarified that source of energy from sea waves, coastal tides and ocean water, are not generally included under the umbrella of 'small hydro' even though hydropower is central to those concepts.

2.2. A brief history

As is the case of most other renewable energy sources which have gained currency during the last two decades, small hydro is not something that has been invented recently [67] but is, in fact, one of the technologies mankind has been using since centuries (just as it has been using wind energy, biomass energy, geothermal energy and direct solar energy). Indeed hydropower is one of the oldest methods of producing mechanical power, even if generation of hydroelectricity began only in the 19th century [32]. In the form of watermills hydropower is in use since ages throughout the world. For example in the UK, water mills are known to have been in use over 900 years ago. Their numbers grew with time and by the 19th century, there were over 20,0000 water mills in operation in England alone [37]. In Europe, Asia and parts of Africa, water wheels were used to drive a variety of industrial machinery, such as mills and pumps. The invention of the water turbine in France in 1827 led to the development of modern hydropower. In Europe turbines replaced the waterwheel almost completely by the end of the 19th century.

In the USA, the first hydroelectric scheme was installed in Wisconsin in 1882, only three years after the light bulb had been invented by Edison [38]. In India, the first-ever small hydro unit for

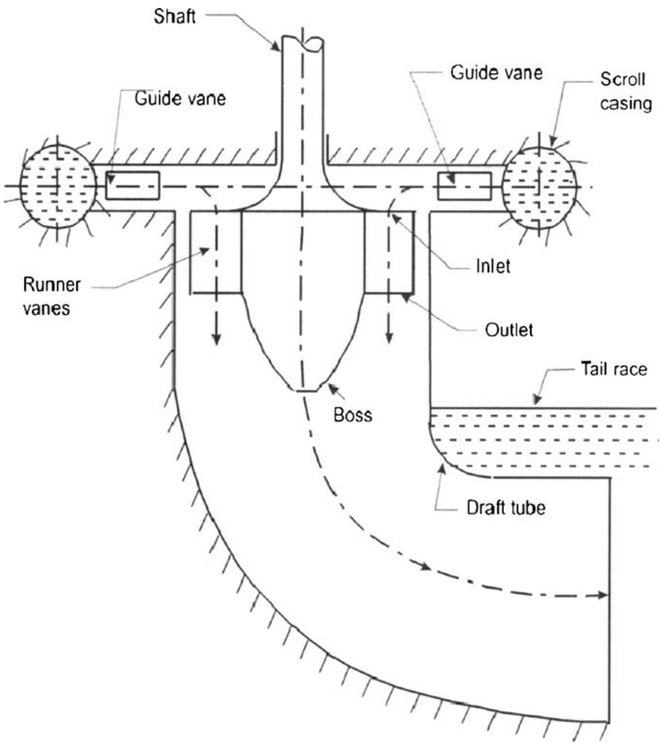

Fig. 1. The Kaplan turbine.

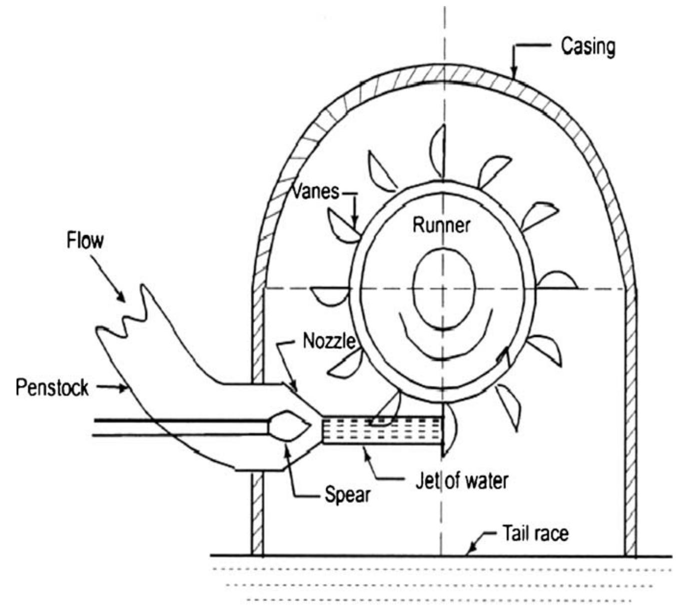

Fig. 2. The Pelton wheel.

generating electricity (unlike watermills which used water power directly in getting the work done) was commissioned in 1897, at Darjeeling. It had a capacity of 130 kW and is operational even to this day! Another small hydropower unit of 4.5 MW capacity came up at Sivasamudram, in 1902. It had the express purpose of supplying power to the Kolar gold mines. In the pre-independence India a substantial proportion of the then installed capacity of 508 MW of hydropower came from small and medium units. After independence the focus was on large projects leading to a total hydropower generation capacity of 21,000 MW. Of these, small hydro contributed only about 500 MW.

2.3. Technologies available

Design of small hydro is not merely the miniaturization of larger hydropower systems of which the technology has been advanced to near perfection. For this reason efforts to improve the design of small hydro units is continuing to be made across the world, aiming at cost-effectiveness coupled with better suitability to the conditions prevailing at different types of sites [39]. Numerous options, now available include:

Turbine – propeller, Kaplan (Fig. 1), Francis, cross-flow, or Pelton (Fig. 2).
Governor – hydraulic, solid-state, or programmable logic controllers.
Material for penstocks – steel, concrete, concrete with steel lining, rock tunnel, woodstave, open channel, high density polyethylene, or glass fibre.
Civil structures – Pre-fabricated material (saving construction time), or locally available material/labour.
Design – modular and standardized, or customized.
Equipment – off-the shelf or tailor-made
Controls – manually operated or remotely supervised.

The wide variety of technologies being used is illustrated with the example of India, in Table 2.

2.4. Present extent of utilization and the potential of small hydro

The global installed capacity for electrical power generation by small hydro was 32,000 MW in 2000 and is expected to rise by about 40% to reach 45,000 MW by the end of 2010 [32]. As per European Renewable Agency council [40], small hydro is contributing about 47,000 MW of electric power at present. Europe, with about 13,000 MW of this installed capacity, is the second biggest utilizer of small hydro, just behind Asia [41].

Another estimate, in terms of power generation equivalent to a million ton oil use, shows a twofold increase in the contribution of small hydro, from 9.5 in 2001 to 19 in 2010 [42]. Estimates may vary but there is no argument over the fact that the world at present is utilizing a very small fraction of the small hydropower potential (SHP). For example India has SHP of about 15,000 MW but only a tenth of it has been tapped so far [36]. Indonesia has an estimated SHP of 500 MW but only 5 MW has been installed and just 1 MW is being actually used [43].

Bangladesh has a SHP of close to 10,000 MWh but almost zero utilization [44]. Given that Asia leads the world as the biggest small hydropower generating continent, such gross underutilization of this resource in Asian countries reflects an even greater gap between SHP and its realization elsewhere in the world.

It is the cognizance of this fact, and the presently well-entrenched belief that small hydro is a clean and ‘green’ source of energy, with none of the environmental problems that besiege large hydro, has generated a world-wide surge of interest in tapping SHP. China is already the biggest user of its SHP, with over 0.1 million systems currently in operation [45] and plans to tap it even more. Other countries, including two the world’s fastest growing economics – India and Brazil – are putting in place increasingly ambitious plans to tap their SHP [46–49]. Alongside wind energy, small hydro is the fastest growing renewable energy option for electricity supplies in Canada [50]. The European Union’s new member states have only about a tenth of small hydro capacity compared to the EU-15 nations, but plans are afoot to increase it substantially [51].

Table 2
Technologies being used in the small hydropower systems installed in India.

Name of the project	Capacity (kW)	Net head (M)	Civil works			E & M works			
			Type of scheme	Water conductor system	Gate/valve	Turbine	Control	Powerhouse	Generation voltage (kV)
Andhra Pradesh									
Gundur BC–II	2 × 2150	8.5	Canal	Opendrop	Gates channel	S type Kaplan-do-	Digital	RCC+S-do-	1111
Lockinsula	2 × 2000	12.2	-do-	-do-	-do-	-do-	-do-	-do-	3.3
Karnataka									
Mala Prabha	2 × 1200	10	Canal	-do- drop	-do-	S type semi-kaplan	-do-	-do-	3.3
Shiva	2 × 1500	8.3	-do-	-do-	BV	-do-	-do-	RCC + M	3.3
Dhupdal	2 × 1400	4.8	Dam toe	Penstock	Gates+ BV	S type kaplan	-do-	RCC + S	3.3
Shahpur–1	1 × 1300	6.2	Canal	-do- drop	-do-	-do-	-do-	-do-	3.3
Shahpur–2	1 × 1300	6.2	-do-	-do-	-do-	-do-	-do-	-do-	3.3
Shahpur–3	1 × 1300	6.2	-do-	-do-	-do-	-do-	-do-	-do-	3.3
Shahpur–4	1 × 1300	6.2	-do-	-do-	-do-	-do-	-do-	-do-	3.3
Shahpur–5	1 × 1400	9.8	-do-	-do-	-do-	Francis	-do-	-do-	3.3
Anveri	2 × 750	22	-do-	-do-	Gates	S type kaplan	-do-	-do-	11
Hemavathy	4 × 4000	16	Dam toe	Penstock	Gates+BV	S type semi- kaplan	-do-	-do-	3.3
Maddur	2 × 1000	13.2	Canal	-do-	Gates	-do-	-do-	-do-	3.3
Mudhol	1 × 1000	13.1	-do-	-do-	-do-	-do-	-do-	-do-	3.3
Deverebalekare	2 × 1000	10.9	Dam toe	Penstock	-do-	-do-	-do-	-do-	3.3
Kerala									
Western Kallar	1 × 3000 +2 × 1000	66	R–O–R	-do-	Gates+BV	Francis	-do-	-do-	6.6
Karikkayam	2 × 7500	20	-do-	Penstock	-do-	Vertical kaplan	-do-	-do-	11
Ullungal	2 × 3500	10	-do-	Penstock	-do-	S type kaplan	-do-	RCC + M	6.6
Boothathankettu	4 × 4000	9.5	Dam toe	-do-	Gates	S type kaplan	-do-	-do-	11
Kuthungal	3 × 7000	134	R–O–R	Pressure	-do-	Francis tunnel	-do-	-do-	11
Tamil Nadu									
Periyar Vaigai	3 × 2200	17	Canal	Opendrop	-do- channel	S type semi- kaplan	-do-	-do-	11

There are two types of beliefs about the environment-friendliness of small hydro; both are widely prevalent:

(a) That small hydro is all 'green' – it has no adverse environmental impact at all [30,31,33,52–55].
(b) That small hydro does have some negative impacts but the impacts are too small to be of any concern [8,29,32,36,46,56].

Considering the grave dangers posed by global warming and the very urgent need to find cleaner alternatives to fossil fuels, one would fervently wish that the confidence being placed with the environment-friendliness of small hydro is justified.

But a careful assessment of situations that would arise once small hydro is used extensively, in the form of large number of units operating across large areas, leads to serious apprehensions discussed below. It would be in the larger interest of really gainful realization of SHP that we confront these apprehensions right away, see the possible pitfalls, and develop SHP in a manner that the numerous likely adverse effects are prevented from occurring.

3. How environment friendly small hydropower systems really are?

Authors and agencies who do mention the likely adverse impacts of small hydropower systems (SHS), also simultaneously pre-suppose that such impacts are inconsequential. No scientific basis is given for the belief; the only apparent logic behind the presupposition is that since an SHS is a 'small-scale' system, the adverse impacts it may cause will also be proportionately small. For example while counting benefits of SHS, MNRE [36] has stated that SHS are – *environment-friendly because they cause negligible or no submergence; minimal deforestation; and minimal impact on flora, fauna, and biodiversity*. MNRE does not give any justification for its beliefs but is echoing very similar sentiments expressed with similar absence of any basis, by other advocates of SHS. For example Kosnik [8] states 'the negative riverine impacts of hydropower dams diminish with plant size... small or micro hydropower systems have extremely minimal riverine impacts'.

In its report on the environmental implications of various renewable energy sources, the International Energy Agency, based at Paris, notes [7]: Small scale hydro schemes tend to have a relatively modest and localized impact on the environment. These arise mainly from construction activities and from changes in water quality and flow on ecosystems (aquatic ecosystems and fisheries) and on water use.

After the reassuring first sentence, IEA [7], surprisingly goes on to list a very large number of adverse impacts SHS are likely to cause on the environment. These impacts encompass the environment upstream SHS, at the SHS, and downstream SHS. The aquatic as well as the terrestrial environments are shown to be under risk of disruption due to SHS, in terms of physical, chemical, and biological factors:

- Most of the impacts from construction are typical of any civil engineering scheme: temporary disruption from transport of materials, noise, visual intrusion, dust, etc. There are additional impacts in the aquatic environment, including increases in suspended matter and turbidity, although well planned operations can minimize these.
- The flooding of land may affect agriculture, local infrastructure and archaeological or conservation sites. However, the area of land flooded for small scale projects is not large.
- The construction of a weir or dam may cause some ecological disruption to the river flora and fauna and to surrounding vegetation. However, the construction period is short – at the most a year.
- For some schemes (e.g. retrofitting of existing dams), aeration levels can be reduced, which can have a detrimental effect on aquatic ecosystems. Dissolved oxygen levels can affect fisheries, decreasing growth rates or causing mortality among sensitive species.
- For high-head schemes there may be detrimental effects due to the reduced flow between the abstraction point and the point where water returns, which may lead to a deterioration in water quality, changes in habitat availability and possible concentration of pollutants. This can be reduced if minimum flow levels are determined before construction and maintained during operation.
- The alteration of water flow, such as broadening of stream bed and reduction of current may lead to indigenous fish species being reduced or replaced. Nitrogen super-saturation (which causes gas bubble disease in fish) can occur in high-head schemes if air is inadvertently entrained along with diverted water. Projects can be designed to minimize such problems and so good practice should avoid potential impacts.
- Hydro schemes may change the level of suspended solids in the river water and affect siltation, erosion, visual amenity and aquatic ecosystems. This could have consequences for flooding and for water supply at any abstraction point downstream of the scheme. The changes in suspended solid levels may affect a number of fish and other aquatic species, particularly during spawning.

IEA [7] further observes: 'It should be noted that, in most schemes, all the above effects are small and can be mitigated by appropriate design techniques. Moreover, hydro installations have some beneficial effects on river systems. In particular:

- They collect and remove a large amount of water-borne debris during operation;
- Water flow is slower leading to less erosion of the river bank;
- Upstream water levels can be raised'.

After the mention of these three potentially beneficial impacts on the environment, IEA again lists several potentially adverse impacts:

- Of the potential impacts, those on fish populations are generally perceived to be the most important. The greatest of these is on migratory species, because the hydro power scheme can create or increase obstruction to their migration. Similarly, hydro schemes can also present a barrier to the downward migration of smolts and non-migratory fish.
- For well developed sites, the visual intrusion of small-hydro schemes is minimal. Nonetheless, these effects, whilst small, can be important, as suitable sites for small hydro schemes may be in environmentally sensitive areas or areas of natural beauty. The storage reservoir for low head schemes or the long channel for high-head schemes will have a visual impact but this can be mitigated by use of local materials, screening and careful site selection. For all types of schemes, buildings and structures provide one of the most obvious sources of visual impact. However, sympathetic design, the use of existing buildings and traditional design and materials should all minimize the potential visual impact from these structures.
- The ecology of an area around a low-head scheme can also be affected permanently by the establishment of a mill-pond behind the dam;

- Small-scale hydro schemes may affect recreational activities, although the overall balance of benefits and disbenefits can vary from scheme to scheme;
- Wastes from running the plant (e.g biocides and anti-fouling preparations for pipe cleaning) can pollute the water. Good operating practices (e.g. use of biodegradable compounds) can minimize the impact of releases to the environment;
- Hydro power developments may impact on flood defences and it may be necessary to compensate for any obstructions to flow and in-filling of the flood plain, for example by providing additional flood plain storage;
- There is a small risk of damage from dam failure, though such events are extremely rare.

IEA [7] then concludes: 'The impacts of small-scale hydro schemes are likely to be small and localised, providing best practice and effective site planning are used'. Elsewhere it notes, 'overall, the impacts of small-scale hydro schemes on aquatic ecosystems are likely to be extremely small and localised'. In a similar vien Kosnik [8] has included 'negative riverine effects' among the 'costs' of SHS but has added that these 'negative. . .effects. . .are minimal'. Varun et al. [56] have put SHS alongside wind as the 'most sustainable source for electricity generation' by assuming that SHS contribute only 31–75 CO_2/kWh by way of greenhouse gas (GHG) emissions. But these estimates do not account for all significant carbon emissions from SHS [34], and the picture may change if the global warming contributions of methane and nitrous oxide are factored in. Even more significant may be other adverse environmental impacts which the authors have simply not considered. With a similar system of logic Chhetri et al. [55] have deemed SHS 'sustainable in the long term'.

3.1. How can we be sure the impacts will be small?

Even as IEA [7] is candid enough to list nearly all the adverse environmental impacts associated with SHS which, by now, are in fact well documented in literature with reference to large hydro, IEA has pre-supposed, without the aid of any hard evidence, that 'these impacts are *likely* to be small and localized'. Then, perhaps realizing that there is no basis for such a pre-supposition, they have added the words, 'provided best practice and effective site planning are used'. But what exactly constitutes 'best practice'? What makes for 'effective site planning'? There is great uncertainty and impracticability associated with these concepts. Firstly what we call 'best practice' at any point of time is dependent on the extent of our grasp of the situation at that point of time. Till a couple of decades back 'best practice' for thermal power projects *vis-a-vis* gaseous emissions meant control of SO_x and NO_x. Control of CO_2 was not a major concern at all. Likewise no existing set of 'best practice' guidelines for hydropower or geothermal projects carry any instructions to deal with methane or N_2O emissions.

A few decades back the use of methyl-tart-butyl ether (MTBE) as an additive to gasoline was considered a 'best practice' *vis-a-vis* reduction of vehicular pollution because MTBE allowed more complete combustion of gasoline and consequently reduced vehicular emissions. But, by-and-by, it was discovered that MTBE entails serious risk of water contamination because it enters groundwater more easily than other gasoline components after a leak or spill. MTBE was originally chosen for its relatively low cost compared with other alternatives, but how costly this presumption has turned out to be can be gauged from the fact that MTBE remediation efforts may consume $1 billion to $3 billion [65,68]. Another example is the unanticipated adverse consequences of spills of ethanol–gasoline mixtures. The greater biodegradability and cosolvent effect of ethanol, originally presumed to be preferable to MTBE as an oxygenate, have been subsequently found to cause build-up of higher and more persistent concentrations of monoaromatic hydrocarbons (benzene, toluene, ethylbenzene, and xylene) in contaminated groundwater [69].

The second reason is that 'best practice' is a contextual phenomena: what is best practice for a city, state, or country is not necessarily a best practice for another city, state, or country. Given this reality, even national consensus on 'best practice' is difficult to arrive and what is agreed upon gets deviated here and there due to compulsions of accommodating conflicting interests. The prospect of achieving global consensus *and commitment* on truly 'best practice' appear remote.

If best practice is difficult to specify it is very difficult to legislate, and, on the ground, almost impossible to enforce. Experience has taught us this. In the country where the authors work, India, very elaborate and strict norms for 'best practice' exist for all kinds of developmental activities. Technology, manpower, and other resources to implement the 'best practice' are also available. No industry, power project, or any other developmental activity is allowed without elaborate EIA and written commitments that best practices shall be followed [28,70,71]. Despite all this numerous factors operate to cause major deviations from the 'best practice'. There are governmental agencies and non-governmental watchdog groups to prevent this but even the task of randomly policing a statistically significant number of operators is so huge that across-the-board enforcement of 'best practice' has been impossible. A recent example is the failure of three state governments in India to implement the environmental safeguards stipulated by the Supreme Court of India when the Court had permitted two large hydropower projects on the Narmada River, subject to the condition that those safeguards will be implemented. An Expert Committee set up by India's Ministry of Environment and Forests has now reported that the compliance to the various best practice stipulations by the three concerned state governments has either been highly inadequate or absent altogether [57]. The severe environmental damage that has occurred is largely irreversible. Instances like this abound across the world which is why environmental activists tend to be skeptical in the face of assurances that a potentially harmful project will be made harmless by implementing appropriate protective measures.

Moreover by stating 'subject to best practice' one can justify any and every technology. One can say even for the most hazardous of activities: 'it will cause no harm provided best practice and effective site planning are used' [72].

3.2. Likely scenario when SHS are put to widespread use

What would be the scenario if small hydro is put to widespread use? Let us again look at the prevailing expectations and try to see how realistic they are and where the likely pitfalls are.

Presented below, are a set of arguments culled mainly from a review authored by the Executive Director of Indian Renewable Energy Development Agency, New Delhi [73]. The author's comments are presented below each of the arguments.

Argument (A): Small hydro is more consistent compared to other renewables like wind, solar, biomass with regard to its availability for power generation – even run-off-the river schemes can have small pondage to meet the daily peak requirement of power.

Comment (C): Interestingly similar arguments continue to be advanced by other proponents of SHS. For example Kosnik [8] maintains that 'Small and micro hydropower is much more reliable than alternative renewable, such as solar or wind power. The sun goes down at night and for much of the winter, and in any given day can spend a lot of time behind cloud coverage. Wind is also variable, intermittent, and unpredictable. Small and micro hydro-power sites can be winterized to provide power throughout the year, when these other renewable cannot be counted'. Evans

et al. [34] also put SHS in more favourable light compared to some other renewables in this respect. But the fact is that if wind energy depends on wind, and solar energy on sun-shine, hydro energy too depends on availability of water. During summer when power needs are generally higher than the rest of the year, all hydropower schemes can suffer from loss of capacity utilization if the water level in the storage reservoir falls (which often *does* happen). A run-of-the-river scheme would be even more susceptible to water availability, whether it has facility of a storage pond or not. Shallow reservoirs and ponds such as the one that accompany small hydro are likely to dry up quicker than deeper reservoirs used in large hydropower projects. Lastly it is not quite correct to club biomass with wind, solar, and hydro as examples of 'inconsistent sources', because it is very easy and inexpensive to store biomass energy by just stockpiling the biomass when it is available aplenty for using it later. Water for use in generating hydropower cannot be stored away in godowns as biomass can be. It has to be stored only by creating artificial lakes or ponds which will have all the adverse environmental impacts associated with such reservoirs.

A. (a) Cost of generation from small hydro would be less than half that of thermal power plants; (b) real capital investment is less than that of thermal (power plants); (c) on the basis of project life cycle costs in real terms, small hydro becomes several times cheaper than the thermal option.

C. Even if we accept all the assumptions/presumptions that have led to the above mentioned results *vis-a-vis* cost of small hydro compared to thermal power, it tells nothing about cost of small hydro relative to medium and large hydro. By using conventional wisdom about the economics of scale, one would imagine small hydro to be significantly costlier per kilowatt of energy generated. Furthermore the positive attribute, that small hydro can provide power in remote and hilly localities, carries with it the logistic problems of providing support for maintenance and trouble-shooting in remote areas.

A. Small hydro projects are generally environment friendly and non-polluting. They do not involve serious deforestation, rehabilitation, and submergence. However, depending on the site and the layout of the scheme, trees may have to be removed in marginal areas. This is invariably compensated by afforestation of equivalent area or double the area of degraded forest. These projects do not involve construction of dams and therefore, generally no rehabilitation problems arise. However, in case of formation of small pondages and also any removal of habitation along the diversion canals, etc. suitable arrangements are made in consultation with the government authorities. Pollution and related negative effects are not expected in hydro projects. However, the projects pass through the pollution clearance mechanisms of the state governments and also the forest clearance in case of involvement of forest lands. The effect on the downstream water supply and drainage is one of the important concerns which is addressed during the SHP design. The dry area of the stream of canal from the diversion structure till the tail race *vis-a-vis* the water needs of habitat for drinking and irrigation, and effects on aquatic and fish life are to be studied in detail. Necessary compensatory measures like provision of separate drinking water, irrigation lines, fish ladders, etc. are to be incorporated in the design to mitigate such impacts.

Due to the environmentally benign nature of these small schemes and to reduce the time involved in clearance procedures, MoEF has exempted hydel projects with an outlay of less than Rs 500 million from environmental clearance.

C. This passage is liberally peppered with 'however'. As in the case of the views of IEA [7] and other authors detailed earlier, there is expression of optimism, but the basis for it is not given. The mitigation measures – rehabilitation, compensatory afforestation, provision for fish ladders, etc, – are the ones always mentioned by the proponents of larger hydropower projects as well. But we all know that their effectiveness, in practice, has been far below the expectations.

Of particular concern is the statement – "Due to the environmentally benign nature of these small schemes... the government has exempted hydel projects... of less than Rs 500 million from environmental clearance." Are we not taking the environmentally benign nature for granted? In fact with the increasing use of SHS, their adverse impacts have already begun to surface and voices of opposition to SHS are already beginning to be heard [58]. In the New England and the Northwest regions of USA there is a growing popular movement to dismantle small hydropower plants in an attempt to restore native trout and salmon populations [9].

These authors are worried (and would be extremely glad to be proved wrong) that once a large number of small hydropower schemes become operational their adverse environmental impacts shall come to the fore.

By all reasoned assessments the environmental problems caused by small hydro look small in comparison to large hydro only till they are considered on the scale of impact *per* kilowatt of power generated. Once this is done, it emerges that the problems that would be caused due to widespread use of SHS would be no less numerous, and no less serious, *per kilowatt generated*, than those from centralized hydropower.

Among the factors to consider in making a comparison are the reach of river habitat affected by the interruption of water flow, barriers to animal movement in the water, water loss from evaporation, wilderness quality of the sacrificed portion of river, and the amount of access road needed. With smaller dams, storage is an increasingly important problem and could lead to the necessity for constructing more low-head systems than anticipated. The problems of siltation and eutrophication which are common with major reservoirs are likely to be even more serious with smaller and shallower bodies of water created by mini and micro projects [28,63]. Lastly the emission of greenhouse gases is as likely to occur from shallow reservoirs – which are similar to paddy fields known to contribute substantially to methane emissions [59–62,64] – as from large reservoirs, if not more.

All things considered the environmental impacts of smaller and dispersed hydropower projects are not likely to be so insignificant as to make them a viable alternative to large hydro *for widespread use*. It is a moot point whether the adverse impacts of a large number of small hydro would be only as severe as, or worse than, the impact of the 'known devils' – large hydropower projects of equivalent capacity.

4. Summary and conclusion

Small hydropower systems (SHS), as the name suggests, are smaller versions of medium-scale and large-scale hydropower systems (LHS). Within the SHS umbrella come 'small', 'mini', 'micro' and 'pica' hydropower systems representing increasing degrees of smallness.

It is a strongly prevalent belief that SHS have none or little of the adverse environmental impacts that are associated with LHS and that SHS represent a very clean source of energy. This belief, and the fact that only a very small fraction of the existing global potential of SHS has been realized, have generated very strong initiatives in several countries to tap the potential of SHS.

In the present work, after giving an overview of SHS, the authors have addressed the question, are SHS as environment-friendly as is widely believed at present? The experience with LHS has been recounted bringing out how, in the early 1950s when much less number of LHS were in existence and the adverse impacts of LHS were still to be documented, LHS were perceived as clean and green source of energy much the same way SHS are being perceived

now. But once a larger number of LHS went into operation and their adverse impacts were encountered again and again across the world, the perception changed. The authors have then proceeded to explain that even as the belief in the environment-friendliness of SHS is very strong and widespread, it has no rational basis. Indeed, all things considered, assessments of the environmental problems caused by small hydro look small in comparision to large hydro only till they are considered on the scale of impact *per* kilowatt of power generated. Once this is done, it emerges that the problems that would be caused due to widespread use of SHS would be no less numerous, and no less serious, *per kilowatt generated*, than those from centralized hydropower.

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